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Parallel bispectrum phase reconstruction for large-format astronomical imaging detectors

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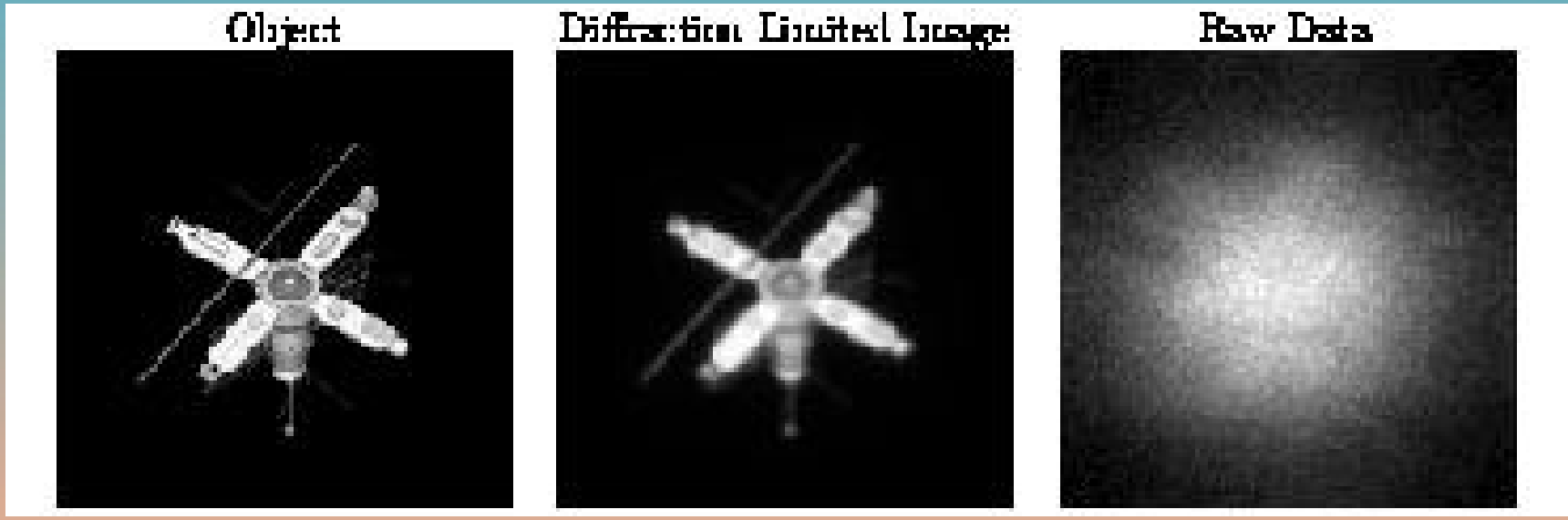
Space surveillance and the Earth's atmosphere

- Handy for breathing; pesky for space surveillance at near- and mid-infrared and visible wavelengths



Producing high-resolution imagery using ground-based telescopes

- Post-detection processing (PMP)
  - mathematical inversion of the blurring effect ("deconvolution") after measurements are made
- Adaptive optics (AO)
  - real-time sensing and correction of blurring effects *before* detection
- "Hybrid" imaging (Roggemann, Tyler, and Fox 1992)
  - post-detection processing of AO images
  - nearly always residual blurring after AO!

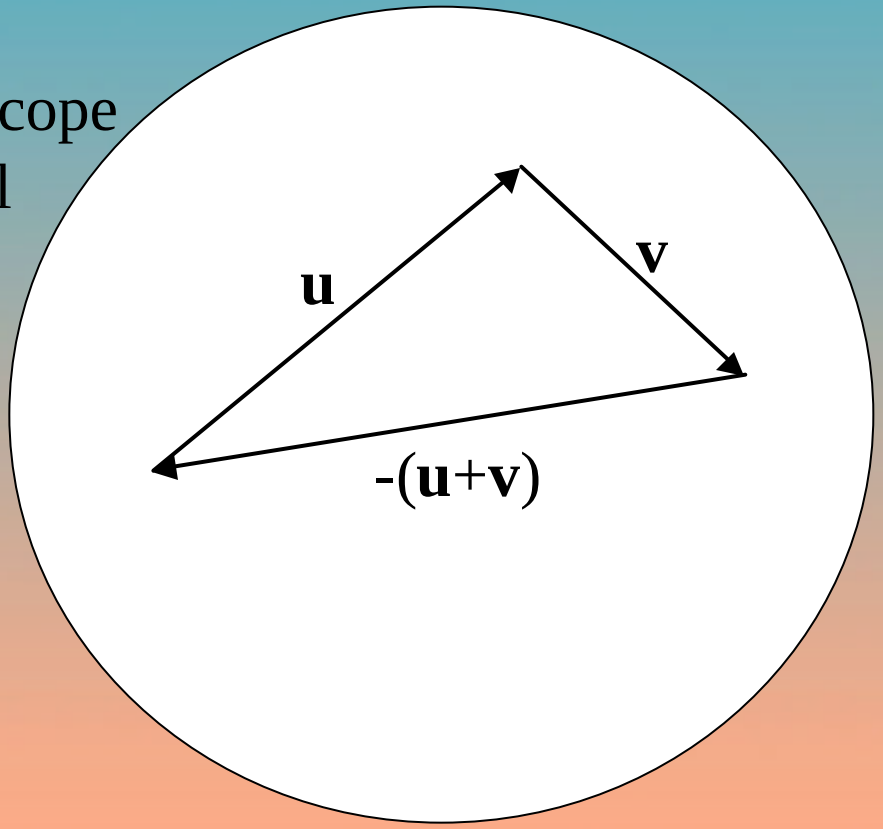
"Speckle" imaging

- Really two techniques--
  - estimation of the object *amplitude* spectrum
    - "Speckle interferometry" or "Labeyrie's technique"
  - estimation of the object *phase* spectrum
    - phase recovery from the "bispectrum"
- Both methods employ mathematical quantities formed from the image data
  - "power" spectrum better conditioned to inversion than complex image spectra
  - *the phase of the* image *bispectrum is the same as the phase of the* object *bispectrum!*

What is the bispectrum?

Also know as the "triple correlation: $B(\mathbf{u},\mathbf{v}) = I(\mathbf{u})I(\mathbf{v})I^*(\mathbf{u}+\mathbf{v})$

telescope pupil



How does the bispectrum yield the object phase?

$$\arg\{B(\mathbf{u},\mathbf{v})\} = \arg\{I(\mathbf{u})I(\mathbf{v})I^{*}(\mathbf{u}+\mathbf{v})\} = \arg\{O(\mathbf{u})O(\mathbf{v})O^{*}(\mathbf{u}+\mathbf{v})\}$$

admits the use of the "deconvolution"

$$f(\mathbf{u}+\mathbf{v}) = \arg\left(\sum_{\mathbf{u},\mathbf{v}}\left[\frac{w(\mathbf{u},\mathbf{v})B(\mathbf{u},\mathbf{v})}{O(\mathbf{u})O(\mathbf{v})}\right]^{*}\right)$$

called the "recursive" algorithm

The phase recovery algorithm

- Note that to estimate the phase at the frequency **u**+**v** using the deconvolution equation in the previous slide, the correct phases at **u** and **v** must already be known!
- The algorithm must be started by assuming the phases near "DC" (zero spatial frequency) are zero and then proceeding outward in radius from the pole
  - reasonable for a "real" object intensity
  - Other algorithms offer iterative solutions for the phase starting with all zeroes or a random phase distribution

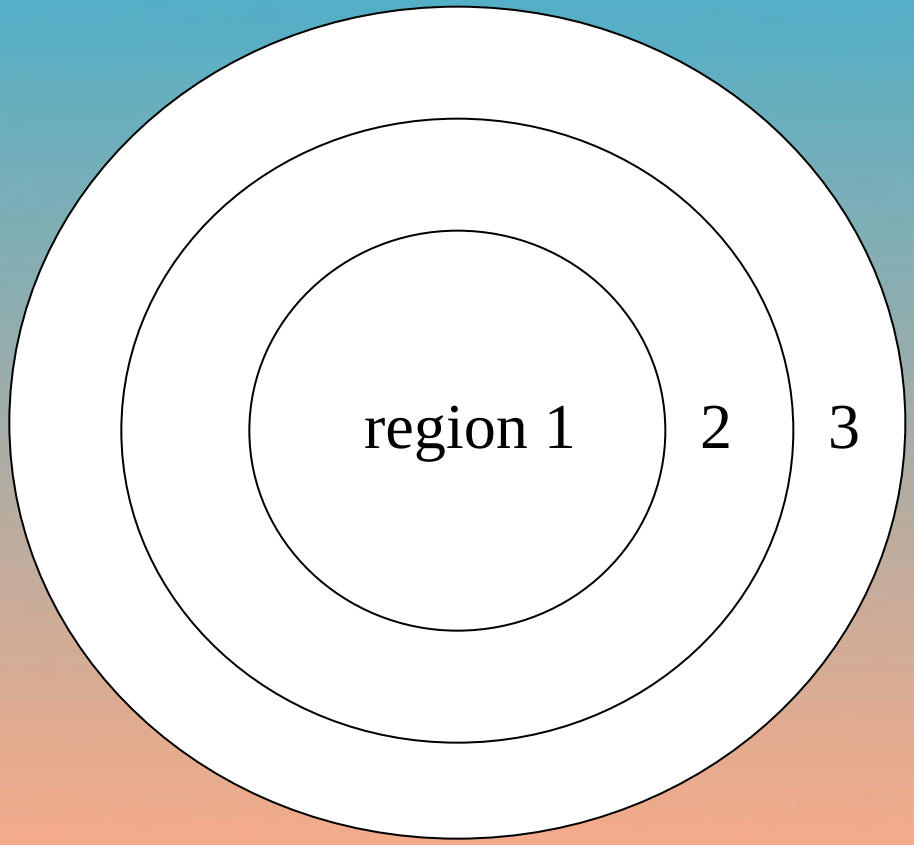
Computational shortcomings

- Memory:
  - with new large-format (512^2 pixels) detectors and decent seeing, the number of bispectrum elements can be as large as hundreds of millions
- Speed:
  - while calculation of the average bispectrum from an "ensemble" of image frames can be parallelized, no one has parallelized any of the phase recovery algorithms due to the dependence of the solution phase on already-estimated phases

The "part-bispectrum:" A new approach to the phase solution

- 1. Calculate on several nodes only those bispectrum elements needed to estimate the phase within some small radius about zero spatial frequency
- 2. While estimating the associated phases, calculate the bispectrum elements needed to estimate the phases in a small annulus around the original radius
- 3. Use the new set of bispectrum elements and the phases estimated in Step 2. to estimate the phases in the annular region
- 4. And so on...

The "part-bispectrum:" A new approach to the phase solution



The "part-bispectrum:" A new approach to the phase solution

- The number of bispectrum elements in memory at any time can be controlled by selecting the number of "part-bispectra"
- Speed is increased by accomplishing multiple bispectra calculations and the phase recoveries in parallel
- Drawback: Fourier transforms of all image frames in the data ensemble are held in memory
  - OK for small ensembles (typical with AO data); still much smaller memory requirement
  - data can be read and phases estimated in stages for large sets

Status

- New algorithm coded and results compared with old code
- Load balancing for various ensemble sizes and calculation of speedups underway